

Conservation tillage and energy

RONALD R. ALLEN, B. A. STEWART, and PAUL W. UNGER

IN 1970 the United States used the equivalent of 46.3 million barrels of crude oil daily to meet its energy needs (4). This energy was supplied by a variety of sources: hydroelectric power, nuclear power, natural gas, and coal as well as crude oil.

While the country's food system consumed 12 to 15 percent of this energy, agricultural production accounted for less than 3 percent of the total. Agricultural production included production-related activities prior to that point when the material lost its identity as a farm product. For example, a grain of wheat was a farm product, but a wheat flake was not.

Of the energy used for agricultural production, farm power consumed less than half directly. The remainder was consumed indirectly to manufacture and deliver production inputs, such as fertilizers, chemical supplies, and machines. Table 1 provides a breakdown of the total energy use for the U. S. food system.

The Costs of Energy

Although agricultural production accounts for only a small portion of the

Ronald R. Allen is an agricultural engineer, B. A. Stewart is research leader, and Paul W. Unger is a soil scientist at the Southwestern Great Plains Research Center, Agricultural Research Service, U. S. Department of Agriculture, Bushland, Texas 79012. This article, a contribution from Soil, Water, and Air Sciences, Southern Region, ARS, in cooperation with the Texas Agricultural Experiment Station, Texas A&M University, was presented at the 31st annual meeting of SCSA in Minneapolis, Minnesota.

nation's energy use, this use represents a critical need among producers. Energy and related costs increased rapidly from 1973 to 1976. For example, the price of diesel fuel about doubled, reaching 40 cents per gallon by 1976. Fertilizers, such as anhydrous ammonia (82 percent nitrogen), increased in price from about \$100 to \$200 or more a ton. New farm machinery and related repair costs increased 40 to 50 percent. During the same period, U. S. petroleum imports increased from about 25 to 40 percent of our national use.

With the pressures of limited energy and higher costs, along with increased demands for food and fiber, minimum tillage and no-till systems can help reduce fuel energy requirements and related expenses. These systems were not originally planned for energy conservation, but for conserving soil and water resources and improving production efficiency.

On the Great Plains, efficient use of limited water must interrelate with tillage systems. Drought on the Great Plains in the 1930s caused extensive wind erosion. Stubble-mulch tillage was developed to protect the soil. Stubble mulching employs shallow primary tillage with a sweep, chisel, or disk to leave crop residues on the surface or partially mixed with the surface soil. This practice was the forerunner of many reduced tillage systems, which have since spread beyond the Great Plains for use with small grains and other crops (19).

Stubble-mulch tillage research at Bushland, Texas, began in 1942 (11). Research also has been conducted with reduced tillage systems under furrow irrigation since 1968. This work has included fuel energy measurements. Average values for specific operations are presented in table 2. Actual fuel requirements for each field operation vary with soil type, moisture content, and tillage depth.

We discuss here conservation tillage systems and their effects on energy use at Bushland and at other locations in the Great Plains, Midwest, and East-Central farming regions. The tillage energy requirements for other locations are estimates based on reported field operations and use of agricultural machinery management data (2). To simplify discussion, we express energy use in diesel fuel equivalents. In internal combustion engines a gallon of diesel fuel will do the work of about 1.4 gallons of gasoline or 1.65 gallons of LP gas.

Water Conservation and Energy

At Bushland, stubble-mulch tillage of dryland wheat residue using sub-till sweeps stored 1.5 inches more soil water during 15 months of fallow

Table 1. Energy use in the U. S. food system (4).

Function	Energy Used (%)
Agricultural production	18
Food processing	33
Transportation	3
Wholesale and retail trade	16
Household preparation	30

Table 2. Measured average diesel fuel consumption for specific field operations, Pullmay clay loam, Bushland, Texas.

Operation	Tillage Depth (in)	Diesel Fuel (gal/a)
Dryland Sweep	3	0.65
Sweep	5	0.90
Surface-irrigated		
Moldboard plow	8-10	3.00
Heavy tandem disk	3- 5	1.00
Heavy offset disk	3- 5	1.25
Lister bedder		0.70
Disk bedder		0.90
Rolling cultivator		0.55
Chisel, 15-in. space	6- 8	1.5-1.8
Chisel, 20-in. space	6- 8	1.30
Chisel, 40-in. space	6- 8	0.80
Sweep-rodweed (bed-furrow cultivation)		0.85
Seeding		
Grain drill, 10-in. space		0.40

and produced 13 percent greater yields than one-way disk tillage (11). Table 3 summarizes yields, soil water storage, and fuel use. The yield and soil water storage values represent 27- and 12-year averages, respectively. Fuel requirements for one-way tillage averaged about the same as with sweeps. However, sweeps provided greater production efficiency because of the higher yields.

Research in Nebraska compared draft requirements of V-sweep and one-way tillage on wheat and oat residues (6). The one-way system required more power in weed-free stubble. Sweeps required more power in weedy stubble. In relatively light (2,200 pounds per acre) 6-inch oat stubble, sweep tillage maintained about 70 percent of the residue on the surface. One-way tillage maintained about 35 percent. With 16-inch wheat stubble (5,300 pounds per acre), both implements maintained about the same amount (55 percent) of surface residue after one tillage operation.

A study at Archer, Wyoming, compared the energy requirements of bare fallow (one-way followed by sweeps and rodweeder) with stubble-mulch tillage (sweep and rodweeder) (8). Both tillage treatments (with wheat) required about the same energy.

With irrigated wheat residue at Bushland, herbicide control of fallow season weeds and volunteer wheat was compared with clean tillage. During the fallow period between wheat harvest in June and the following spring, 2.5 inches more water was stored and about half as much fuel was used with herbicide control (18). Table 4 compares soil water storage and fuel requirements for three tillage-herbicide treatments. The 2.5 inches of extra stored water nearly equalled that normally stored with a preplant irrigation and greatly reduced the need for an irrigation before seeding sorghum or corn. The energy savings for one irrigation amounts to about 13 gallons of diesel fuel per acre or 20 percent of the 64-gallon-per-acre average fuel use for seasonal irrigation of sorghum at Bushland.

Table 5 lists the tillage effects on yields, irrigation water use, and fuel requirements of furrow-irrigated grain sorghum. With the bed-mulch treatment, old stalks stood undisturbed until spring. A sweep rod-weeder was used to cultivate beds before seeding

the new crop. The sweeps undercut and cleaned the furrows, while a counter-rotating, 1-inch-square rod undercut the beds. In the bed-split treatment, new beds were formed over the old furrows.

The reduced-tillage treatments—bed-splitting and mulching—required about half as much fuel and increased yields by 13 and 20 percent, respectively, compared with the clean-tilled disk treatments. Irrigation water use

efficiency with bed-mulching and bed-splitting was 13 percent greater than with disking.

Table 5 also shows the results of no-till seeding of grain sorghum, double-cropped after winter wheat harvest, at Bushland. No-till required about one-third as much fuel as clean tillage and increased average grain yields 12 percent (1). No-till seedlings grew more rapidly at early stages and remained about five days more

Table 3. Yield, fallow season soil water storage, and fuel requirements for dryland wheat, Bushland, Texas (11).

Tillage	Yield ^a (lb/a)	Soil Water Storage ^b (in)	Fallow Efficiency ^c (%)	Diesel Fuel ^d (gal/a)
Continuous wheat				
One-way	520	1.59	20	3.4
Sweep	610	1.78	22	3.4
Wheat-fallow				
One-way	830	2.54	10	6.4
Sweep	940	4.04	15	6.4

^a27-year average, 1943-1969.

^b12-year average, 1958-1969.

^cPercentage of fallow season precipitation stored. Continuous wheat with a 3-month fallow period. Wheat fallow with a 15-month fallow period.

^dSweep-till fuel measured; fuel for one-way till estimated (6).

Table 4. Fallow season soil water storage and fuel requirements with varying tillage, Bushland, Texas (18).

Treatment	Number of Operations	Soil Water Storage (in)	Diesel Fuel (gal/a)
Disk	4	3.1	4.00
Sweep	4	3.4	2.85
Herbicides ^a	1	5.6	1.90 ^b

^a3 lb. atrazine, 1 lb. 2,4-D.

^bDiesel equivalent energy to produce and apply herbicides (12); atrazine = 0.57 gal. diesel/lb. A.I.; 2,4-D = 0.30 gal. diesel/lb. A.I.

Table 5. Yield, irrigation response, and fuel requirements for annual and double-cropped grain sorghum with varying tillage, Bushland, Texas.

Tillage	Grain Yield (lb/a)	Irrigation Water Use Efficiency (lb/a-in)	Diesel Fuel ^a (gal/a)
Annual cropped (1975)			
Disk-chisel (disk × 2, chisel—8", disk, chisel NH ₃ —6", lister bed, preplant bed cultivation, plant)	5,310	287	7.30
Disk (disk × 2, chisel NH ₃ , lister bed, preplant bed cultivation, plant)	4,850	262	6.10
Bed split (chop stalks, lister split beds, furrow chisel NH ₃ , bed furrow cultivation—rolling cultivator, plant)	5,500	297	3.40
Bed mulch (furrow chisel NH ₃ , bed-furrow cultivation—sweep-rodweeder, plant)	5,860	300	2.50
Double-cropped after winter wheat (1968-1973)			
Clean-till	4,520	213	5.4
No-till	5,075	240	1.5

^aIncludes diesel equivalent energy to produce and apply herbicide (atrazine).

advanced in growth throughout the season. The time required to prepare a seedbed and plant no-till was one-fifth as much as clean tillage. This time saving is a key to successful double-cropping in the Southern High Plains. More time was saved by delaying nitrogen application until after plant establishment and applying ammonia as a sidedress application.

At North Platte, Nebraska, herbicide treatment increased soil water storage and reduced fuel requirements compared with conventional stubble-mulch tillage (sweep) for

fallow season weed control (17). The wheat-sorghum-fallow sequences consisted of two crops in three years with about 11 months of fallow between crops. Table 6 shows estimated fuel use, soil water storage, fallow efficiency (percent of precipitation stored), and grain yields. Herbicide treatments reduced fuel use by 27 percent and increased soil water storage by 20 percent over sweep tillage. Succeeding wheat and sorghum yields were greater following fallow season weed control with herbicides.

No-till seeding through a killed sod

cover increased corn yields in Kentucky (10) and Virginia (16). The sod cover reduced surface evaporation during the first 40 days until the crop canopy developed, permitting more rapid early growth. Yields increased from 117 to 126 bushels per acre in Kentucky and from 80 to 103 bushels per acre in Virginia. Estimated fuel requirements to prepare the seedbed and plant corn at both locations were 5.5 gallons of diesel fuel per acre for clean tillage and 2.5 gallons for no-till.

Erosion Control and Energy

Stubble-mulch tillage reduced soil loss from wind erosion in western Nebraska (7). Soil loss averages for eight years were 0.9, 1.4, and 2.9 tons per acre, respectively, for sweep, one-way, and moldboard treatments on a wheat-fallow rotation. The initial moldboard tillage required about 50 percent more energy than the sweep or one-way systems (2).

Studies at Madison, South Dakota, showed that reduced tillage decreased water-born soil erosion on a 5.8 percent slope (14). Soil loss averaged 2.69, 1.63, and 1.57 tons per acre under conventional, mulch, and disk-till corn planting treatments with up-and-down-hill rows, respectively. Fuel requirements to till and plant the treatments were estimated at 5.5, 4, and 3 gallons per acre. Corn yields were 58.6, 64.9, and 62.8 bushels per acre.

At Coshocton, Ohio, five years of no-till results showed that average corn yields increased from 104 to 116 bushels per acre, while average soil losses on 9 percent slopes declined from about 1,500 to 25 pounds per acre (9). We estimated fuel requirements for tillage and planting at 4 gallons of diesel fuel per acre for clean tillage and 0.5 gallon per acre for no-till. The diesel fuel equivalent for herbicide treatment was about 1.5 gallons per acre for clean tillage and 2.5 gallons per acre for no-till. This brought the fuel requirement totals to 5.5 and 2.5 gallons per acre.

Crop Production Energy Inputs

To this point we have discussed only comparisons of fuel requirements for tillage and planting under various systems. Table 7 illustrates the equivalent energy requirements needed to produce and harvest surface-irrigated and dryland grain sorghum at Bush-

Table 6. Fallow season soil water storage, fuel requirements, and grain yield with sweep tillage and herbicide weed control, North Platte, Nebraska (17).

Tillage	Number of Operations	Soil Water Stored (in)	Fuel ^a (gal/a)	Fallow Efficiency ^b (%)	Yield (lb/a)	
					Wheat	Sorghum
Sweep	8.5	7.3	5.5	35	3,110	3,640
Herbicide	6.0	8.8	3.0 ^c	42	3,240	4,480

^aEstimated.

^bPercent of fallow season precipitation stored.

^cEstimated diesel equivalent energy to produce and apply herbicides.

Table 7. Fuel energy equivalents required for surface-irrigated and dryland grain sorghum tillage systems, Bushland, Texas.^a

Operation	Irrigated				Dryland	
	Disk Chisel	Disk	Bed Split	Bed Mulch	Wheat-Sorghum-Fallow	Continuous Sorghum
	diesel fuel equivalent, gal/a					
Till and seed	7.30	6.10	3.40	2.50	4.4	3.0
Fertilizer ^b	21.00	21.00	21.00	21.00		
Herbicide	1.10	1.10	1.10	1.10	0.5	0.5
Irrigation ^c	64.10	64.10	64.10	64.10		
Harvest	1.2	1.2	1.2	1.2	0.75	0.70
Transportation	0.8	0.8	0.8	0.8	0.20	0.15
Total	95.5	94.3	91.6	90.7	5.85	4.35

^aAssumed yield levels: 115 bu/a (6,500 lb/a) irrigated, 27 bu/a (1,500 lb/a) dryland sorghum phase (wheat-sorghum-fallow), 20 bu/a (1,100 lb/a) dryland continuous sorghum.

^b150 lb/a N as NH₃—0.14 gal. diesel fuel per lb. N equivalent for NH₃ (13).

^c20-acre-inches, 250-ft. pump lift, 75 percent pump efficiency, 95 percent gear head efficiency.

^d250 bu. load, 10-mi. round trip to market, 4 mpg (gasoline).

Table 8. Fuel energy equivalents required for irrigated and dryland corn production with varying tillage systems in Nebraska (20).

Operation	Irrigated			Dryland		
	Conventional Tillage	Till-Plant	Slot-Plant	Conventional Tillage	Till-Plant	Slot-Plant
	diesel fuel equivalent, gal/a					
Tillage and seed	4.1	1.5	1.0	4.1	1.5	1.0
Fertilizer	30.2	30.2	30.2	21.7	21.7	21.7
Chemicals	1.1	1.1	1.4	1.1	1.1	1.4
Irrigation	30.9	30.9	30.9			
Harvest	1.1	1.1	1.1	1.1	1.0	1.1
Drying	13.7	13.7	13.7	8.2	8.2	8.2
Transportation	3.0	3.0	3.0	1.8	1.8	1.8
Total	84.1	81.5	81.4	38.0	35.4	35.2

land, Texas. This includes tillage, seeding, fertilizer and herbicide applications, irrigation, harvesting, and transportation to nearby grain elevators. Under irrigated production, tillage and planting energy amount to only 3 to 7 percent of the total. Fertilizer and irrigation pumping require the most energy. With dryland production, tillage and seeding use 70 to 75 percent of the total energy. Although tillage energy with irrigation is only a small part of the total requirement, saving 3 to 4 gallons of diesel fuel per acre, along with time and labor, is certainly worthwhile.

Table 8 reviews the energy requirements for corn production under various tillage systems in Nebraska (20). Projected dryland corn yields are for eastern Nebraska, where rainfall is greater than in the Western High Plains portion of the state. Under these conditions, dryland corn requires about half as much energy as irrigated corn. As in Texas, fertilizer and irrigation account for the major share of energy used. However, the irrigation energy requirement is less in Nebraska than in Texas because of a lower specified pumping lift. Actual irrigation pumping depths and related costs vary considerably within states as well as among states.

Energy requirements and production costs in the Manhattan, Kansas, vicinity have been reported for tillage systems similar to those used in eastern Nebraska. Herbicides slightly increased the costs of limited tillage systems (up to \$3.00 an acre), but reduced the energy requirements of growing grain sorghum (5). Using 1974 prices, tillage costs (machinery, labor, herbicides) for conventional, till-plant, and no-till systems were \$15.11, \$15.90, and \$18.44 per acre, respectively. Till-plant and no-till reduced the energy requirements to 62 and 70 percent of conventional tillage.

Tillage Trends and Energy

There has been a general trend to less intensive primary tillage during the past 10 years. Chisel-plow and chisel-disk systems have replaced some moldboard plowing. This has been the result of efforts to reduce the time and cost of primary tillage (15). Energy requirements are directly proportional to the amount of tillage.

Tillage practices on irrigated soils

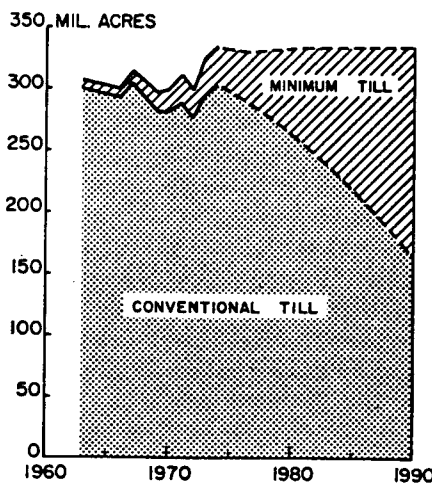


Figure 1. Estimated area of planted cropland in the United States with projected trend in type of tillage (19).

in the Southern High Plains have followed the national trend away from moldboard plowing to chiseling. We estimate that moldboard plowing and disking use about 1.5 gallons per acre more diesel fuel than chiseling and disking on a fine-textured clay loam under surface irrigation. The elimination of one disking or cultivation not essential for weed control could save 0.5 gallon of diesel fuel per acre (3). On this basis, the elimination of one field operation on 25 percent of the nation's 1973 corn and soybean acreage (129 million acres) could have saved about 16 million gallons of diesel fuel equivalent.

The Soil Conservation Service has estimated that the acreage in minimum tillage increased from 3.8 million in 1963 to 33 million in 1974 (19). For these estimates, the general definition of minimum tillage is "limiting the number of cultural operations to those that are properly timed and essential to produce a crop and prevent soil erosion." The U. S. Department of Agriculture (19) has projected that nearly half of the nation's more than 300 million acres of planted cropland could be managed by minimum tillage and no-till by 1990 (Figure 1). These projections anticipated continued advances in technology. Further adoption of conservation tillage, as projected, would surely enhance soil and water conservation and lower fuel energy requirements. However, savings in farm machinery-related energy costs are likely to be offset by the added costs of pesticides.

REFERENCES CITED

- Allen, R. R., J. T. Musick, F. O. Wood, and D. A. Dusek. 1975. No-till seeding of irrigated sorghum double cropped after wheat. Trans., ASAE 18: 1,109.
- American Society of Agricultural Engineers. 1976. Agricultural machinery management data. In *Agricultural Engineers Yearbook*. St. Joseph, Mich.
- American Society of Agricultural Engineers. 1975. To conserve energy in agriculture. Agr. Eng. 56(5): 17-19.
- Barnes, K. K. 1974. The CAST report: Energy in agriculture. Agr. Eng. 55 (2): 19; (3): 19-22; (4): 37-39; (5): 21-23.
- Clark, S. J., and W. H. Johnson. 1975. Energy-cost budgets for grain sorghum tillage systems. Trans., ASAE 18: 1,057-1,060.
- Dickerson, J. D., N. P. Woodruff, and C. R. Fenster. 1967. Power requirements, cloddiness, and residue conservation characteristics of some stubble-mulch tillage implements. Bul. No. 152. Kans. Agr. Exp. Sta., Manhattan.
- Fenster, C. R., and T. M. McCalla. 1970. Tillage practices in western Nebraska with a wheat-fallow rotation. Bul. No. 597. Nebr. Agr. Exp. Sta., Lincoln.
- Fornstrom, K. J., and C. F. Becker. 1976. Energy requirements and machinery performance for four summer fallow methods. Paper No. 76-1020. Am. Soc. Agr. Eng., St. Joseph, Mich.
- Harrold, L. L., G. B. Triplett, and W. M. Edwards. 1970. No-tillage corn—characteristics of the system. Agr. Eng. 51: 128-131.
- Hill, Jerry D., and R. L. Blevins. 1973. Quantitative soil moisture use in corn grown under conventional and no-tillage methods. Agron. J. 65: 945-949.
- Johnson, W. C., and R. G. Davis. 1972. Research on stubble-mulch farming of winter wheat. Cons. Res. Rpt. No. 16. U. S. Dept. Agr., Washington, D. C.
- Jones, D. P. 1974. Energy considerations in crop protection. Outlook on Agr. 8(3): 141-147.
- Miles, J. A. 1975. Energy savings through alternative fuel utilization in desert agriculture. Paper No. 75-1004. Am. Soc. Agr. Eng., St. Joseph, Mich.
- Onstad, C. A. 1972. Soil and water losses as affected by tillage practices. Trans., ASAE 15: 287-289.
- Oschwald, W. R. 1973. Chisel plow and strip tillage systems. In *Conservation Tillage*. Soil Cons. Soc. Am., Ankeny, Iowa. pp. 194-202.
- Shanholtz, V. O., and J. H. Lillard. 1969. Tillage system effects on water use efficiency. J. Soil and Water Cons. 24: 186-189.
- Smika, D. E., and G. A. Wicks. 1968. Soil water storage during fallow in the Central Great Plains as influenced by tillage and herbicide treatments. Soil Sci. 32: 591-595.
- Unger, P. W., R. R. Allen, and A. F. Wiese. 1971. Tillage and herbicides for surface residue, maintenance, weed control, and water conservation. J. Soil and Water Cons. 26(5): 147-150.
- U. S. Department of Agriculture, Office of Planning and Evaluation. 1975. Minimum tillage, a preliminary technology assessment. Washington, D. C.
- Wittmuss, H., L. Olson, and D. Lane. 1975. Energy requirements for conventional versus minimum tillage. J. Soil and Water Cons. 30(2): 72-75. □